In Indiana we have surely developed a "professional consciousness." We have done quite a bit toward enforcement of the registration act. We have an adopted code of ethics. We now have four local chapters in addition to our state chapter and state society. In the last session of the state legislature, we sponsored three bills. With the able guidance of Engineer Clyde Walb and others, two of them were enacted into law, and the third passed the senate and only failed to get final reading in the house. You city engineers are here today at this Road School because of one of those laws; the other created a merit system for all engineers in state employ.

This represents considerable accomplishment by a militant few and in a comparatively short time. How much more could we do with all of us working together for our common good?

APPLICATION OF GEOLOGY TO HIGHWAY ENGINEERING

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It is common knowledge that many thousands of years ago a series of great glaciers covered most of Indiana as well as many other states during a period of exceptionally cold temperature. The ones most important to Indiana are named the Illinois and the Wisconsin. These glaciers left quantities of stone, gravel, boulders, sand, silt, and clay deposited at great depths over most of the state. These deposits are varied in character, assorted in some places but predominantly a complex mixture, and of considerable importance to highway engineers—from the standpoint both of sources of aggregate and of the performance of highways.

It is likewise well known that the period of glaciers was but yesterday in geological time and that the bed-rocks of the state were deposited millions of years before. A great many of these rocks were of marine origin—the deep massive beds of fossiliferous limestone beneath the soil mantle in various parts of the state constituting but one of many proofs of the fact. These bed-rocks—like the glacial drift—are likewise of importance to highway engineers from the standpoint both of aggregate sources and of highway performance.

However, one might very logically ask how much and how practical is information about glacial drift and bed-rock geology. Do roads perform differently on various types of glacial drift? What relationship is there between bed-rock geology and the design, construction, and maintenance of highways? To answer these questions it will be necessary to analyze the character of the various glacial-drift deposits and to consider some of the important features of bed-rock geology.

Since the writer is in no sense of the word a geologist, this paper will be devoted to a review of the Indiana geological literature (obtained largely from the references listed at the end of this report) citing the more important and established fundamentals of geology and to the relationship of these data to highway engineering.

Glacial Drift Geology

For the most part the great ice sheets of importance to Indiana appear to have been formed north of the state. They were of considerable thickness—thousands of feet in fact—and, as a result, were able to exert enormous pressures at the base of the ice sheet. Over a period of several thousand years, a succession of such ice sheets moved in a southernly direction across the great lakes and into southern Indiana. While the enormous mass of ice was moving, a large amount of soil and bed-rock was pulverized and incorporated in the ice sheet. In certain parts of Canada the entire soil mantle, as well as the surface rocks, were carried away and deposited farther south: those of you who have visited Canada may recall that in certain localities the soil mantle is still only a few inches in thickness, even after many thousands of years. Gold, copper, lead, and even some diamonds, which undoubtedly must have come from the bed-rocks farther north, have been found in the Indiana drift.

Other definite proofs of glaciation in Indiana include: (1) the presence of both stratified and unstratified deposits of till similar to those now being deposited by mountain glaciers; (2) the presence of granites, schists, and many other rocks not native to Indiana bed-rocks; and (3) the presence of striated boulders and rocks in the till and striated bed-rocks at the base of the drift.

Deposits of the rock and soil mixtures, contained in the ice sheet, are the results of the melting of the ice. The depths of such deposits in Indiana are known to be as much as five hundred feet, with one hundred feet probably being a reasonably-accurate average figure. Some description of the method of deposition and a review of glacial-drift terms are necessary before describing some of the applications to highway engineering.

Definitions. A *ground moraine* is formed when a glacier melts slowly and its debris is deposited as an irregular sheet. If the debris is heaped in ridges on the edge of the glacier, it is called a lateral moraine; while the ridge of material left at the extremity of the glacier is known as a *terminal moraine.* The water flowing from a melting ice sheet will usually carry a large amount of soil and rock materials, which are deposited over the surface beyond the glacier. If these materials are deposited in horizontal layers, such a deposit is known as an *outwash plain*. *Eskers* are long, winding, gravel ridges, deposited by streams flowing under pressure in channels beneath the ice. *Kames* are short ridges of similar material deposited by glacial streams flowing from beneath the ice, frequently against a terminal moraine. A *loess* is an unstratified silt deposited chiefly by wind action.

Loess Deposits. Loess or wind-blown deposits are prevalent in the southern part of Indiana and are almost entirely confined to the Illinois glacial-drift area. These deposits are situated primarily in the vicinity of the main drainage areas. The material, in general, is loose textured, is composed mainly of silica, and has the general characteristics of a silt soil, particularly when remolded. In an undisturbed state, the material has a peculiar structure containing minute vertical channels. As a result, highway-cut slopes may be made vertical and, in fact, slopes other than vertical usually are unstable. The material may be fairly thick in isolated places. Over a greater part of the area of Indiana, however, it is only from five to ten feet thick.

Moraines in Indiana. Indiana has an extensive morainic system scattered through the glacial drift area. A careful analysis of a glacial drift map of Indiana (Fig. 1) will show that there is a distinct pattern and that there are several primary morainic systems situated entirely in the Wisconsin drift area.

Just inside the Wisconsin drift area and roughly paralleling the southern boundary of this drift is the *Champaign Moraine*. This moraine extends from northwest of Crawfordsville through Hendricks County and south to Johnson County, then eastward through Shelby County, and northeastward through Rush and Henry Counties to Newcastle. According to Leverett[1] the material consists of the following: "Along the chain of moraines the prevailing portion of the surface is boulder clay in which pockets of water-bearing sand and gravel are so common that many wells are obtained at depths of 20 feet. The water-bearing beds do not appear to form continuous sheets; they occur at various horizons and seem to be of small horizontal and vertical extent. Gravel knolls are scattered along the entire length of the chain of moraines and are conspicuous though they occupy a very small part of the surface."

The *Bloomington Moraine* is, in general, north of the Champaign Moraine and derives its name from Bloomington, Illinois. The moraine is first found in western Indiana in Benton County, northwest of Fowler, extends southeastward through Tippecanoe, Clinton, and Boone Counties past the city of Indianapolis in Marion County, and continues northeastward through Hancock and Henry Counties and then eastward from Randolph and Wayne Counties to the Ohio state line. The surface

[1] See reference, page 63.

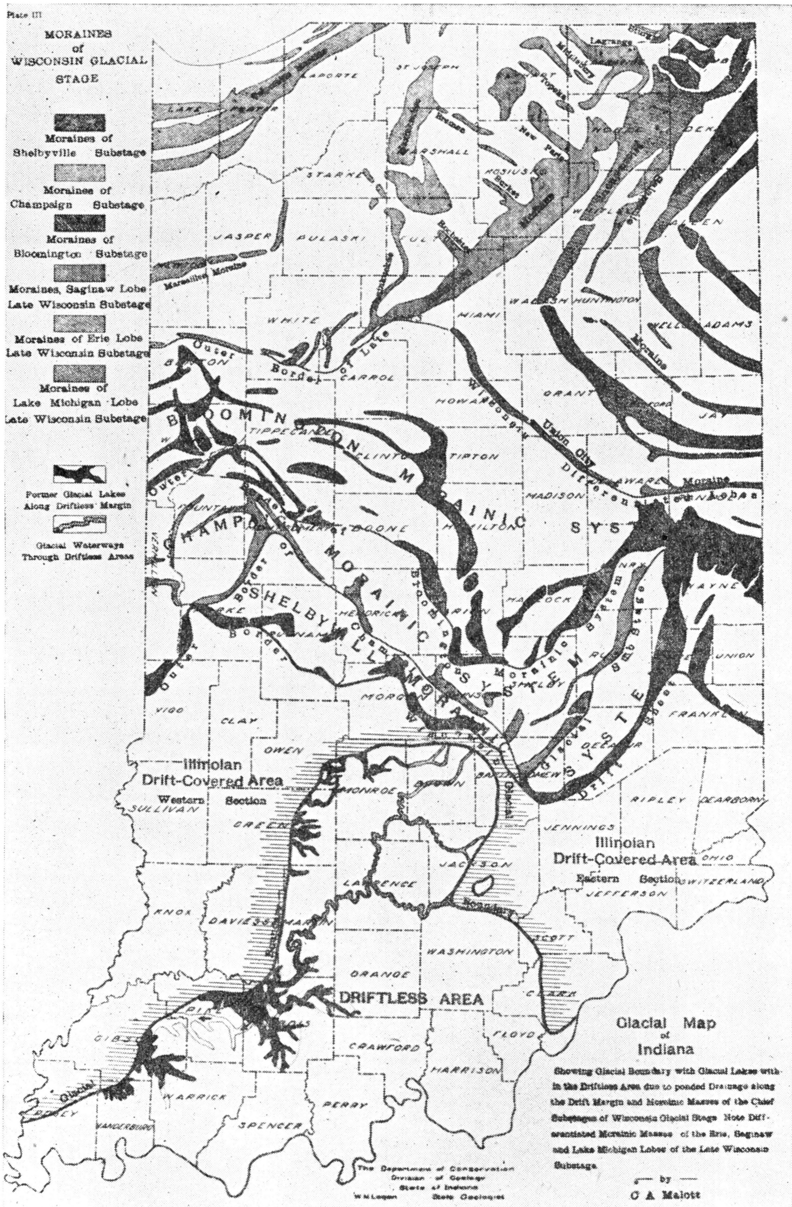

Fig. 1. Glacial drift map of Indiana (from "Handbook of Indiana Geology")

of most of the drift in this area is a till containing a few scattered gravel knolls. The percentage of gravel is generally high, but the gravel is quite frequently mixed with clay, silt, and sands. The gravel is used to a large extent for aggregates in this particular area.

The series of morainic belts in northeastern Indiana will now be discussed briefly: the *Maxinkuckee Moraine,* five to fifteen miles in width, runs from South Bend, Indiana, to a point near Rochester. The southernmost portion of the moraine is composed largely of gravel and sand, the central portion largely of till, with the knolls composed mostly of gravel. The northernmost area is chiefly clayey till.

The *New Paris Moraine* consists of a series of knolls in northeast Kosciusko and central Elkhart County. The moraine is composed of gravel knolls in Noble County and a more clayey till in Kosciusko County, while in Elkhart County there is a considerable accumulation of gravel, particularly near New Paris. A small moraine called the Middlebury is in northeastern Elkhart County and extends southeastward to the southwest corner of LaGrange County. The moraine is composed predominantly of gravel and gravelly till.

The *LaGrange Moraine* takes its name from the village of LaGrange and extends from this point northwest to the northeast corner of Elkhart County. Most of the knolls are composed of gravelly silt, but the more level surface is composed of clayey till.

An extensive series of moraines (*Packerton*) extends northward from the Wabash River at Delphi, Indiana, toward the northeast corner of the state. This rather massive belt shows extensive changes in characteristics of the materials encountered, ranging from heavy clay to coarse gravel. In general, the coarse materials may be found in the outer slopes.

A series of four roughly parallel moraines are found in northeastern Indiana along the Ohio line. These consist of the *Mississinewa, Salamonie, Wabash,* and *Fort Wayne Moraines.* The Mississinewa Moraine extends from the Wabash southeast through Hartford City to the Ohio line, while the Fort Wayne extends from DeKalb County at the Ohio state line to the city of Fort Wayne and through Decatur to the Ohio state line. The other two moraines lie between these two. All these moraines in general consist of clayey till with no great accumulation of sand and gravel.

One of the most imposing moraines of the state is the one called the *Valparaiso Moraine,* which extends from the Illinois line just south of Chicago to the Michigan line, paralleling the Lake Michigan shore. The moraine divides the St. Lawrence and the Mississippi drainages and lies only from five to fifteen miles from Lake Michigan. Its width is from five to twenty miles with an average of seven or eight. At the Illinois-Indiana line the moraine has three distinct ranges, which converge at Valparaiso into one distinct range. The moraine consists predominantly of brown clay till from the Illinois line to Valparaiso. From Valparaiso northeastward, sand and gravel predominate over the till.

Peat Bogs. Peat is found to some extent in all areas of the state covered by the Wisconsin drift, with larger deposits occurring in the three northern tiers of counties. These areas are the result of old glacial lakes.

Peat is usually associated with glacial drift and is common to many countries, including Russia, Ireland, Germany, Sweden, Norway, Holland, France, and China. In the United States the deposits are mostly situated in the northern tier of states within the glacial boundary, in the tier including New Jersey, New York, Pennsylvania, Ohio, Indiana, Illinois, Michigan, Wisconsin, and Minnesota. Their development was brought about by a combination of irregular deposits of till and rough, undrained basins or depressions. The deeper of these basins, those considerably below the ground water table, are our fresh-water lakes, while the more shallow depressions have formed our peat bogs. Peat is the result of plant growth in water and the subsequent decaying of this material during a period of thousands of years. These peat bogs constitute one of the greatest problems of highway engineering in the state.

Major Sand Areas in Indiana. Large areas of the state are covered with sands. These are of considerable importance to highway engineers because of the generally good results obtained by placing pavements on this material and because of their economic use for insulation courses on poor subgrades.

The larger sand areas consist of several major groups, the most important ones being Lake Chicago, Lake Kankakee, and the Wabash Valley basin. The sands in the Lake Chicago area were deposited largely as a result of the old lake. There are three distinct ridges or beaches, named Glenwood, Calumet, and Tolleston. The first mentioned enters Indiana at Dyer and extends east and northeast for several miles; the second, or Calumet beach, lies between the Glenwood beach and the Calumet River, while Tolleston beach lies between the little Calumet and the Grand Calumet rivers.

All the area lying between Tolleston beach and the present shoreline of Lake Michigan is also covered with sand, consisting largely of low beaches, sand ridges, and sand dunes. The dunes are largely the result of wind action, while the beaches and ridges are the result of the former extension of the lakes.

In the Kankakee Lake basin, which covers a large area of the northwest portion of the state, a considerable amount of sand may be found. The sand occurs predominantly as "islands" in this large basin, and the islands are as much as four square miles in area.

In southern Indiana appreciable deposits of sands are frequently found along the east side of streams. Leverett[1] states that they ". . . occur as short winding ridges scattered over a belt from one or two up to several miles in width on the borders of the main valleys. They are very conspicuous east of the Wabash Valley in northern and also in southern Vigo County and are a notable feature south from there through Sullivan, Knox, Gibson, and Posey Counties. Sand deposits are conspicuous along the east side of White River in Gibson and Pike Counties but are more sparingly distributed east of the south-flowing portion of the river in Daviess and Greene Counties and are rather scarce farther north. . . ."

Sand is also found associated with the several morainic systems of the state and probably represents deposits of glacial outwash made during the recession of the ice-sheets.

Glacial Lake Beds. With the retreat of the ice to the north and before the complete melting of the glacier, water was impounded in several large areas in Indiana. After the complete melting of the glacier, several hundred years later, these areas became swamps or, in some cases, dry land. Three very extensive areas are important to highway engineers in Indiana: namely, Lake Chicago, Lake Kankakee, and Lake Maumee.

The Lake Chicago basin occupies a narrow belt just south of Lake Michigan in Lake, Porter, and LaGrange Counties. While the lake was at its greatest height, lake sands were deposited. This deposition was followed by erosion of the moraines, chiefly the Valparaiso Moraine. The coarse materials, such as gravels, were deposited at the base of the moraine, and the fine colloidal materials were carried to the lake before being deposited. The present soil-profile of this old lake bed consists of six or eight feet of very heavy plastic clay now underlaid by clean lake sand. Lakes Maumee and Kankakee were made in a similar fashion with surface soils consisting, in general, of highly colloidal clays. However, in the Lake Kankakee basin wind-blown sands have been deposited over much of the surface.

Preglacial Drainage. The preglacial drainage of Indiana is very difficult to determine because of the extreme depth of the drift. However, from well borings and other information, it is known that the present drainage system of Indiana varies considerably from that present before the advance of the first ice sheet. Preglacial valleys have been located at various places throughout the state. These old buried channels at times have an accumulation of four or five hundred feet of drift material and are of considerable importance to the highway engineer in dealing with large foundation problems. It might be added that these channels are likewise of importance to engineers in the location of dams, in tunnelling operations, in discovering sources of water supply, and in other similar problems.

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[1] See reference, page 63.

Relationship of Glacial Drift to Highways. Detailed information on the glacial deposits are of extreme importance to highway engineers from the standpoint of foundation, subgrades, and cut slopes, and as a source of aggregates.

Foundations. The chief foundation difficulties encountered are concerned with buried channels and peat bogs. Buried channels should be investigated fairly extensively, but no specific rules can be laid down regarding their treatment. Some contain flowing water, while others have pockets of muck or other poor materials.

Peat bogs are likewise troublesome, but they can be investigated systematically. Auger borings should always be made at the proposed center-line to obtain samples of the material throughout the depth, and information on the extent of the material in question. Cross-section borings should also be made frequently, so as to ascertain the shape of the base of the bog.

Subgrade. Subgrade problems may be anticipated and corrected before construction of the highway project by noting the characteristics of the various moraines to be traversed. An inspection of highway surfaces placed in other portions of a given moraine will oftentimes be helpful in determining what type of subgrade treatment should be employed. In general, cuts through moraines do need subgrade treatment in addition to normal treatment for drainage. The most successful treatment, where field studies have shown the presence of poor subgrade conditions, appears to be porous insulation courses extending through the berms and entirely under the pavement. Frost-heaving silts should be excavated for a depth of one or two feet and replaced with a well-drained, granular material.

Cut-slopes and Erosion. The design of cut-slopes from the standpoint of erosion can likewise be associated with glacial-drift deposits. As mentioned previously, the loess deposits should have vertical slopes, while most of the other glacial-drift materials of the state should have flat slopes. With a thorough knowledge of the types of materials that are to be encountered in the moraine, erosion problems can be minimized by corrective treatment installed at the time of construction. Such treatments may include such items as seeding, planting, sodding, and blanket courses such as straw and tree limbs, in addition to carefully-designed drainage systems.

Aggregate Deposits. As mentioned previously, most moraines contain varying quantities of sand and gravels. These deposits are of importance to the highway engineer as well as to the producer of mineral aggregates. A thorough study of the moraine will indicate the amount and availability of the gravels. Also, such deposits are of considerable importance to highway engineers since a thorough knowledge of the availability of unworked granular materials is of economic importance in determining the type and extent of any proposed subgrade treatment.

Indiana Bed-Rock Geology

The exposed geological strata in Indiana total several thousand feet, including exposures of the Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian systems, plus the glacial drift. Approximately 50 per cent of the exposures consist of shale, the remaining portion being limestone, sandstone, coal, and clay. These various formations will be discussed briefly from the standpoint of design, construction, and maintenance of highways.

Ordovician System. The bed-rock exposures of the Ordovician system in Indiana extend from the south border of Switzerland County along the Ohio River northward through Wayne County almost to the Randolph County line. (See Fig. 2.) This outcrop is rectangular in shape and is about 75 miles long (north to south) and about 25 miles wide. The north half of this area is covered with both Illinois and Wisconsin glacial drift, while the southern half is only lightly covered with Illinois drift. Relatively deep highway cuts in the hills will expose bed-rock in most of the entire area.

The Ordovician system is divided into several distinct formations, all of which contain alternating layers of slablike limestone and a very dense argillaceous (clay) shale. Upon weathering, the shale breaks down into a highly plastic clay. The formation is easily identified by the concentration of fossils both in the limestone and in the shale. In fact, this general area of the Ordovician outcrop in Indiana, Ohio, and Kentucky is famous as a source of well-preserved fossils.

This area in general may be considered as dangerous for the construction of highways from the standpoint of foundation troubles, landslides, cut slopes, poor embankment performance, and poor subgrade performance. The cause of most of the difficulty in this general area may be attributed to the combination of the very durable limestone and the very non-durable shale. On the average, the limestone will total less than 50 per cent of the entire formation, with shale being the remaining portion. The limestone occurs in beds from six inches to as much as 10 feet in thickness.

It can be easily seen in considering the characteristics of the formation as described above that the shale weathers and disintegrates rapidly. This process has left a rather deep deposit of disintegrated and unconsolidated shale mixed with limestone boulders. A slight cut in the hillside usually disturbs the equilibrium, and a landslide of major proportions may develop quite frequently. The safe procedure in such areas is to establish the grade line at sufficient depth to be predominantly in bed-rock. Even with this precaution slides may develop in the cut sections.

The construction of embankments from materials in the Ordovician system is a difficult procedure. The hard, durable

Fig. 2. Geological map of Indiana (from "Handbook of Indiana Geology").

limestone is not readily broken down into small pieces, and, as a result, the construction of a dense impervious embankment is quite difficult. One of two procedures may be employed to correct this situation, namely: (1) the removal of the large rock to the outer slopes, thereby permitting construction of a relatively dense impervious embankment; and (2) the breaking up of the larger limestone boulders into small pieces so that they may be readily incorporated in the embankment. Either procedure is costly, but at the same time entirely justified when one considers the fact that one major failure may result in the expenditure of several thousands of dollars in corrective treatments.

Subgrade difficulties are of importance but are not particularly serious. The plastic clay shale is not ideal for subgrades, but the material may be improved easily by using greater compaction in the fill or by special subgrade treatment. Foundation troubles, like subgrades, are only of secondary importance in the Ordovician formation.

Silurian System. The Silurian system is by far the most extensive formation in Indiana. It covers a large portion of the east central part of the state and extends from Fort Wayne to LaCrosse entirely across the state. The formation is largely covered with glacial drift in Indiana and is predominantly limestone. The formation is of considerable economic importance since it is an excellent source of highway aggregates.

Devonian System. This outcrop is a narrow belt 50 to 100 miles in width, extending from Jeffersonville diagonally across the state to the Illinois state line just northwest of Lafayette. The formation consists of two primary materials: namely, (1) the New Albany shale, and (2) fairly deep beds of limestone. The limestone is of economic importance because it is a source of good highway aggregates. The shale is predominantly carbonaceous in character and does not, in general, break down to a plastic material. However, some subgrade difficulties can be anticipated when placing pavements on this material and some trouble may be expected when using the material in embankments, because of the difficulty encountered in consolidation during construction.

Mississippian System. This outcrop is found in a 30- to 50-mile belt extending from the central portion of Indiana along the Ohio River, northwestward to the Illinois line almost due west of Lafayette. The formation consists predominantly of massive beds of sandstone, limestone, and some shale. This formation is famous for the Oolitic limestone beds at Bedford, Indiana. The sandstone in the Mississippian is normally of good quality and causes little or no trouble in side-hill cuts or in fills. The shales are of different types and are always to be questioned, particularly if they are argillaceous.

Pennsylvanian System. The Pennsylvanian outcrop in Indiana is fairly extensive, covering the southwestern part of the state as far north as Attica. The formation is very irregular and complex, consisting of layers of shale, sandstone, limestone, coal, and clay. The formation is of considerable economic importance to Indiana because of the extensive coal beds and the ceramic clays found beneath the coal beds. This formation, like the Ordovician system, is rather dangerous for the construction of highways. Landslides, embankment troubles, and subgrade difficulties are likely to be encountered in any portion of this area where relatively deep cuts and fills are employed. In cut sections landslides caused by strata which are lubricated with water or by unconsolidated surface materials frequently develop. Embankment troubles are likely to be encountered, particularly in the clay, coal, and shale formations. Geological bed-rock profiles are essential for the proper design of the highway in this area when appreciable cuts are employed.

Shales. It can be seen from this brief description of the bed-rock geology of Indiana that the Ordovician and Pennsylvanian formations are by far the most troublesome members. Likewise, it has been indicated that shale formations predominate, and, at the same time, are the most dangerous members of this formation.

Indiana shales may be divided into four general classes as follows: argillaceous (prevalent in the Ordovician); carbonaceous New Albany shale; siliceous (occurring in the Mississippian and Pennsylvanian); and calcareous. The latter three are not likely to be troublesome if they are handled with normal precautionary measures. The argillaceous shales, on the other hand, are quite dangerous, particularly when used as embankment material. The shale is relatively stable as it occurs in its native state; it is quite dense and has a low moisture content. During the excavating process the material may behave almost as rock and during the placing operations will contain a large number of voids between the shale particles. However, in from a few weeks to a few years, such material will generally disintegrate, by weathering, into a very plastic clay.

Shale should be placed in embankments in such a fashion as to pulverize it as much as possible without allowing the material to lose all its natural moisture content. Sufficient soil fines should be used to fill the voids completely, and sufficient water should be added to insure proper compaction at the optimum moisture content. The Proctor density test can be used on the soil fines to control the moisture, but it is practically useless in checking compaction, since the shale particles, which are not pulverized, are nearly as firm and dense as rock.

In conclusion, some of the more important uses of geological information should be mentioned. The bed-rock formations of Indiana as well as the glacial-drift deposits contain an inexhaustible supply of good road-building aggregates. In addition, very satisfactory materials are available for use as porous insulation courses for pavements on poor subgrade. Such materials as the sands, found along most of the western side of Indiana, as well as many of the sandstones of the southern portion of the state, have almost unlimited possibilities for such use. Also, pit-run gravels and crusher-run stones are economic possibilities for such use in areas where sands or sandstones do not occur locally.

A good knowledge of the bed-rock geological literature is almost essential in establishing the grade and alignment of new highways in unglaciated, hilly, or mountainous country. Because of the possibility of landslides, deep cuts and high embankments (especially side-hill fills) are always to be questioned in areas where argillaceous shales predominate. Considerable savings can be made in the design of cut slopes by having advance information on the type of materials that will be encountered. This same information will likewise be helpful in the design and construction of embankments.

Subgrade problems are almost always encountered in glacial-drift deposits. Most of these problems, such as frost heaving, pumping of joints, and drainage problems in general, can be solved, at least in part, by having advance information, obtained by field explorations. At the same time, field work can be made much simpler by utilizing available geological information as well as the more detailed agricultural soil maps. Detailed descriptions of the more important glacial moraines, peat bogs, old lake beds, bed-rocks, and even pre-glacial drainage channels of Indiana are already available in published form.

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